History for Physics: Quantum Foundations

September 23–24, 2019

-Book of abstracts-

Tandem Talks

1. The Weyl-Heisenberg group

Physicist: Irina Dimitru – University of Stockholm

Historian(s): Gonzalo Gimeno and Mercedes Xipell - Autonomous University of Barcelona

Efforts to frame quantum mechanics in a group theoretical framework began in the second part of the 1920's and was reinvigorated after two decades of stagnation[1]. Despite the stagnation, the efforts and vision of the first group of physicists involved in the project turned out to be fruitful, and their initial approach is still visible in the use of groups, in particular the Weyl-Heisenberg group, in contemporary quantum mechanics.

This group, and structures derived from it, are critically important in quantum information and computation; one example is that this is the basic prerequisite for the Gottesman–Knill theorem, which indicates when a quantum computation can be efficiently simulated classically. However, the main use of the group is still along the lines envisioned by Weyl when he introduced the group as long ago as 1925: to define what one might mean by the quantum theory of discrete degrees of freedom.

The Weyl-Heisenberg group in contemporary quantum mechanics

The "physics part" of our talk will focus on applications of this program, in particular in tomography. The group represents a discretization of the phase-space operators, and its elements can be seen as displacement operators in Hilbert space. In this interpretation, the Weyl-Heisenberg group plays an important role in defining both Mutually Unbiased Bases (MUBs) and Symmetric Informationally-Complete POVMs (SICs), two geometric structures that are crucial to quantum tomography, and are indeed used in experimental quantum tomography.

It is remarkable that the practices of experimental physicists identifying prepared states in their labs, together with those of the theoretical physicists studying the Hilbert space from an informational or computational perspective, can so neatly be traced back to the program of fusing group theory into quantum mechanics.

The Weyl-Heisenberg group in historical perspective

---

[1] Scholz, "Introducing groups into quantum theory (1926–1930)." *Historia mathematica* (2006)

The “history part” of our talk will take into account the “physics part” and will try to connect the current uses of the Weyl-Heisenberg group with one of the difficulties that arose in the development of the new quantum mechanics: the problem of continuous spectra. A brief sketch of the history of this problem will be presented and the way in which it got integrated into Weyl’s theory will be drafted. As much as possible we will analyse if current uses of the Weyl-Heisenberg group inherit any of the historical difficulties found during the early years of the theory.

---

2. Quantum Steering

Physicist: H. Chau Nguyen - University of Siegen, Germany

Historian: Otfried Guehne - University of Siegen, Germany

Quantum steering is a notion introduced by Schrödinger in order to capture the essence of the Einstein-Podolsky-Rosen argument. After Schrödinger's work, however, not many people continued to work on it. This changed in 2007, when Wiseman and co-workers introduced a modern formulation, and since then quantum steering has established itself as a central concept in quantum information processing.

In our talks we will present the historical development and the modern approach to quantum steering. In the historical part ("Quantum steering from 1935 to 2007", given by O. Gühne) we will discuss the few works from 1935 to 2007 which tried to extend Schrödinger's approach. Here, it turns out that several results were independently (re)proven by different scientists. In the second part ("A geometric characterisation of quantum steering", given by H. C. Nguyen), we will discuss a current approach to the problem of determining quantum steering, which also allows to connect steering to other topics such as Bell inequalities and generalized measurements in quantum mechanics.

Single (History) Talks

1. Eddington's epistemology – An underrated aspect when looking for quantum foundations?

Agne Alijauskaite - Vilnius University

Eddington's theory of quantum mechanics is still under-discussed in relevant scientific approaches. It is often seen as too "inappropriate" for orthodox debates in physics but this is mainly because of the lack of understanding of Eddington's work.

My aim is to fill this gap at least for some part. This will be done by revising Eddington's theory of quantum mechanics and its relatedness to the general view of cosmo-physics as well as to so-called "theory of everything". My suggestion is to revise his quantum theory through his epistemological views, namely, the notion of "selective subjectivism". I will argue that Eddington's quantum worldview can be understood as an epistemic stance advocating for selective subjectivism because the later defines one's relation to the external world.

Since Eddington claims that "what we comprehend about the universe is precisely that which we put into the universe to make it comprehensible", his epistemic stance inevitably grounds his understanding of quantum mechanics. I will analyze this intersection as a meaningful way to read Eddington's work in contemporary terms, as well as turning to the interpretations of his contemporaries, among who one of the most important figures and supporters is Schrödinger.

---

2. The genesis of the CPT theorem: a study of the generalization of time reversal from classical mechanics to relativistic quantum field theory

Andrés Martinez de Velasco – MPIWG, Berlin

This talk will provide an overview of how the generalisation of time reversal from non-relativistic quantum mechanics to relativistic quantum field theory led to the discovery of the CPT theorem in the mid-1950s.

By considering a space-time reflection (PT) on c-number field theory, Pauli was able to show that a relativistic field theory only really makes sense as a quantum theory in his 1940 paper on the connection between spin and statistic. Going over to q-number theory one has to determine which statistics the different (integer or half-integer spin) fields must follow. In generalizing time reversal (T) from quantum mechanics to quantum field theory (QFT), Julian Schwinger realized in 1951 that a reflection of the time axis implies a reversal of charge (C) for both fermion and bose fields. Further, he found that in QFT one can derive the necessity for commutation rules following the spin statistics theorem from the requirement of time reversal invariance (with C subsumed into T). His work rekindled interest in both the spin statistics connection, which thus far had only been established for free fields, and in the operation of time reversal, leading Gerhardt Lüders to give his own formulation of time reversal in QFT based more closely on Wigner's quantum mechanical formulation. In so doing, Lüders realized empirically that in certain cases, the requirement of time reversal invariance places the same constraints on the interaction Lagrangian as the requirement of charge conjugation invariance. Motivated by this discovery, he took on the task of determining if this equivalence is a general property of QFTs and in so doing formulated the first proof that relativistic QFTs are invariant under the combined transformation of CPT, an idea now known as the CPT theorem. His proof, however, obscured the underlying reasons for CPT invariance and did not concern itself with the relation between CPT symmetry and the spin statistics connection. It would take the hand of Pauli to clarify universal CPT invariance as a consequence of relativistic invariance and the spin statistics connection in 1955, thereby providing firmer footing for the spin statistics theorem in the interacting fields context.

---

3. Bohm's interpretation of quantum mechanics and classicality

Marij van Strien - Bergische Universität Wuppertal (Germany)

Bohm’s interpretation of quantum mechanics has variously been regarded as a reactionary attempt to return to the ideals of classical physics, or as a way to base quantum physics on solid ontological foundations and to do away with many of the puzzling features commonly associated with quantum mechanics. However, Bohm himself always emphasized the non-classical aspects of his interpretation, and argued that rather than a return to classical physics, it provided a way to move beyond current quantum physics towards something more radically new. In his later writings, he connected his work on quantum physics with various speculative and mysticist ideas, even though other authors have used his interpretation of quantum mechanics to argue against quantum mysticism.

In this paper I aim to explain this discrepancy between the ways in which Bohm’s interpretation of quantum mechanics has been received and the way in which Bohm himself spoke about the significance of his ideas. I argue that Bohm’s central commitments were indeed never very classical (in particular, determinism was never the main issue). He was strongly committed to holism and nonlocality, and argued for the need for developing alternative theories and new concepts; he developed general arguments for scientific pluralism in discussions with Paul Feyerabend in 1957-58. Although his interpretation has become known as offering a realist account of quantum phenomena, I argue that Bohm was a realist in some ways, but not in others. A closer look at Bohm’s writings shows the ways in which his interpretation of quantum mechanics is non-classical. Although in Bohm’s account, particles have a well-defined position at all times which can be revealed by measurement, this does not hold for other observables; Bohm argued on this basis that science does not deal with an independently existing reality. Therefore, the idea that Bohm’s interpretation offers a possibility to do quantum mechanics without quantum weirdness may be problematic.

---

4. Schrödinger's struggles with a complex wave function

Ricardo Karam - University of Copenhagen

In this contribution I outline some of Schrödinger's initial resistance to the complex nature of his wave function. It is shown how he first attached physical meaning only to its real component and even tried to avoid the explicit appearance of the imaginary unit in his fundamental (time-dependent) equation. This attitude is quite understandable, since he was committed to the classical framework of wave theory, not only ontologically, but also formally. Around two years after the publication of his famous papers on wave mechanics, Schrödinger seems to have accepted that the wave function must be complex and that the physical interpretation is to be related to its absolute square. This is justified by him both due to equivalence considerations with matrix mechanics and in analogy with Maxwell's equations. This episode can be of special pedagogical relevance as students often struggle with the complex nature of the wave function on their first encounter with it.

---

5. Searching the foundations of quantum statistics: Uhlenbeck's *on the statistical methods in the theory of quanta*, 1927

Daniela Monaldi - York University, Canada

In this paper, I examine the early search for the conceptual foundations of the Bose-Einstein and Fermi-Dirac statistics, focusing on the 1927 doctoral thesis of Paul Ehrenfest's student, George Uhlenbeck. In his thesis and subsequent work, Uhlenbeck carried out and extended Ehrenfest's commitment to the clarification of the enigmas in Boltzmann's legacy and in its relation to quantum theory. He also aimed for mathematical rigour and generality, and took advantage of newer mathematical techniques, as for example the Darwin-Fowler method. Thus, Uhlenbeck's work offers an opportunity to investigate the interaction between the search for conceptual foundations and the evolution of mathematical formalism.